RIVAS Mid Term Conference: "Vibrations - The way ahead"
Venice, 26 October 2012

Transmission path mitigation measures for railway induced vibrations

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- Introduction
  - Objective of RIVAS WP4
  - Methodology
- Test sites
  - Spain: subgrade stiffening next to the track
  - Switzerland: trench barrier
  - Sweden: sheet piling wall
- Conclusions and next steps

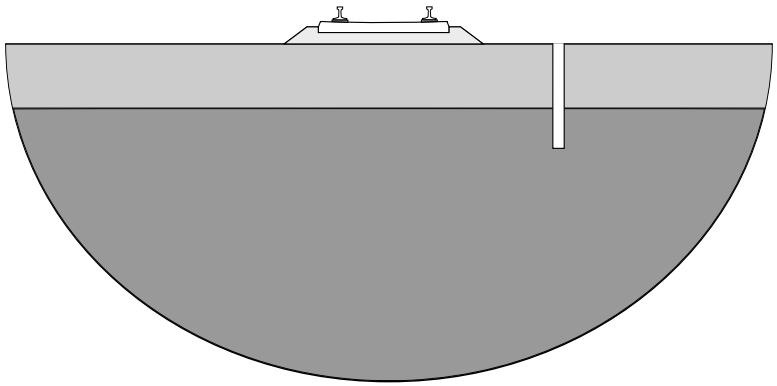
Introduction

- Objective of RIVAS WP4
  - Develop and optimize vibration mitigation measures in the transmission path, either under or next to the track.
  - In the frequency range of railway induced vibration, the top layer of soil plays an important role which is often neglected. It leads to a cut-on frequency above which a steep rise in the vibration transmission spectrum occurs.
  - The key approach is to take the layered structure of the ground into account or alter its effect to impede wave propagation.

- WP4 partners
  - ADIF, BAM, CEDEX, DB, ISVR, Keller, KU Leuven, SBB, Trafikverket

Introduction

- Mitigation measures studied
  - The work concentrates on ballasted tracks and mitigation measures close to the track, so that they are still regarded as part of the track.
  - Options that are studied include:
    - (open) trenches



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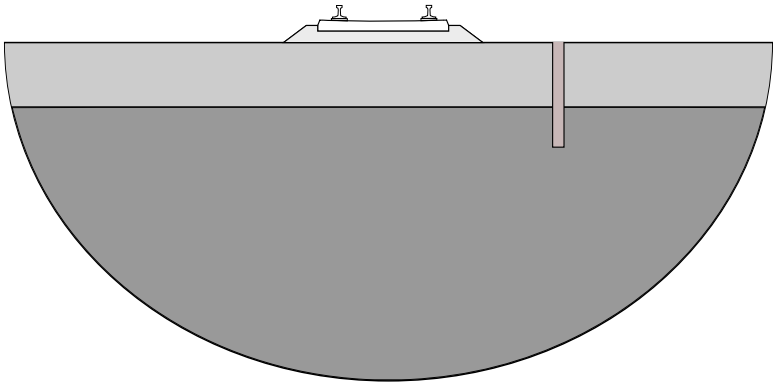

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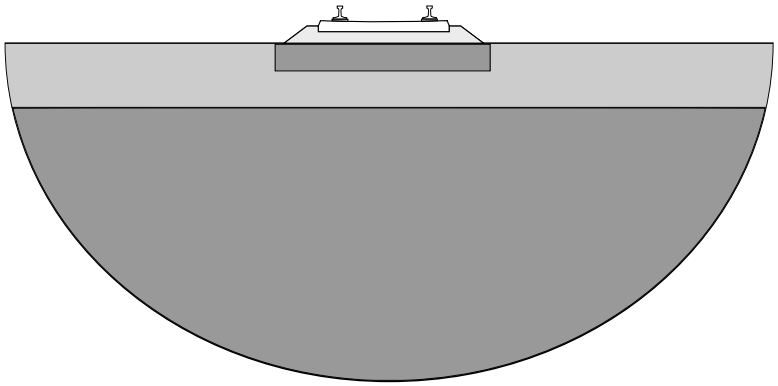
    - stiffening under track



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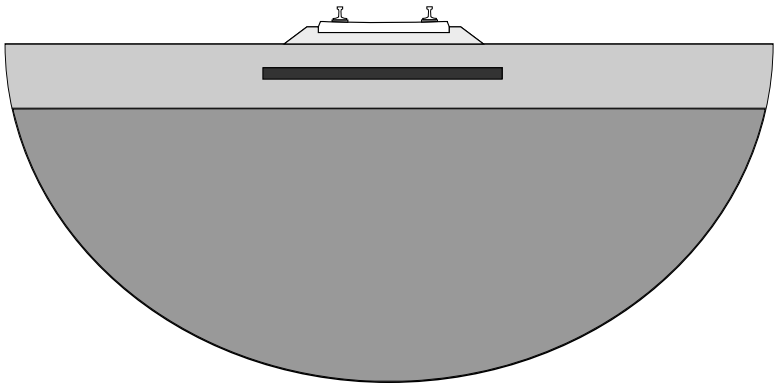
    - wave impeding blocks



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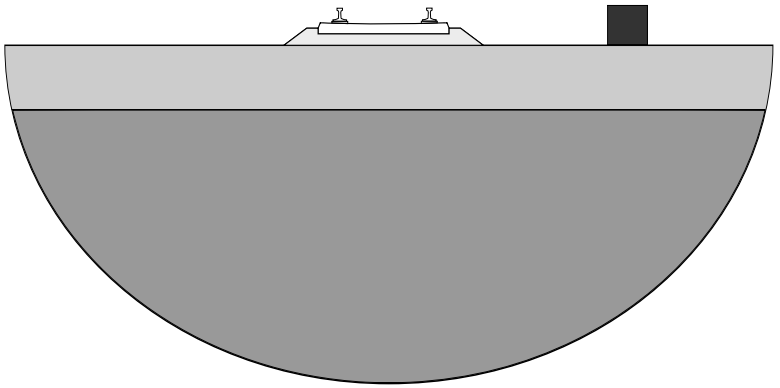
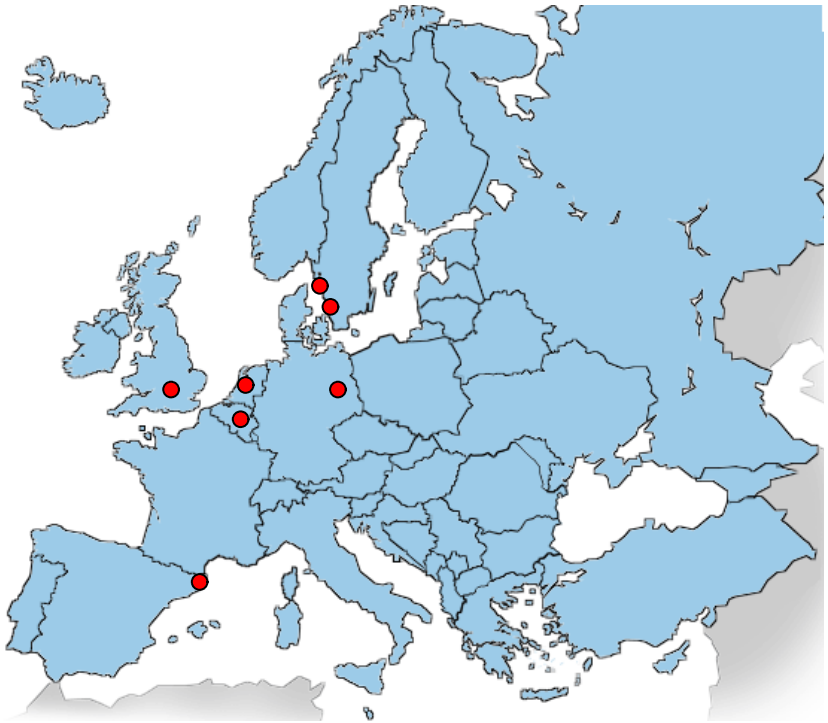
    - stiffening under track
    - wave impeding blocks
    - masses next to track



Introduction

- Methodology
  - Parametric study for a range of possible designs and ground types, representative of sites with problems of low-frequency vibration.



Introduction

- Methodology
  - Parametric study for a range of possible designs and ground types, representative of sites with problems of low-frequency vibration.
  - At least two field tests
    - Soil stiffening next to the track on the ADIF network in Spain
    - Trench barrier on the SBB network in Switzerland
    - Sheet piling wall on the Trafikverket network in Sweden
  - Each successful option will be costed with design guidelines.

Contents

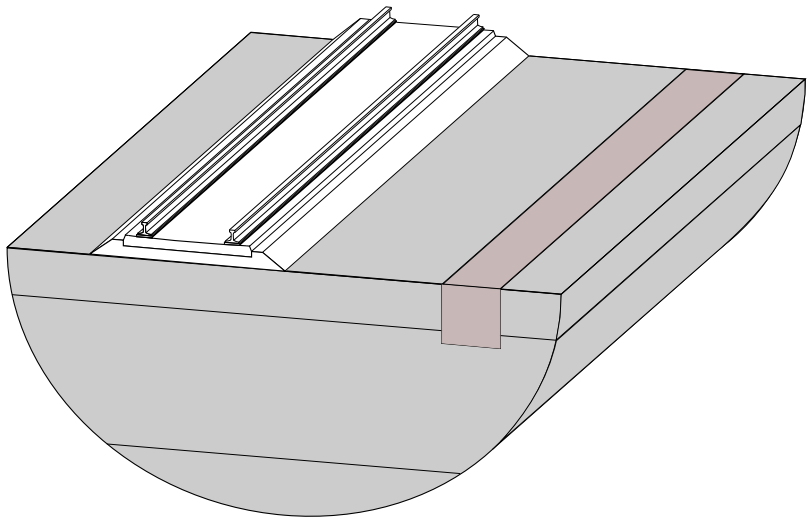
- Introduction
  - Objective of RIVAS WP4
  - Methodology
- Test sites
  - Spain: subgrade stiffening next to the track
  - Switzerland: trench barrier
  - Sweden: sheet piling wall
- Conclusions and next steps

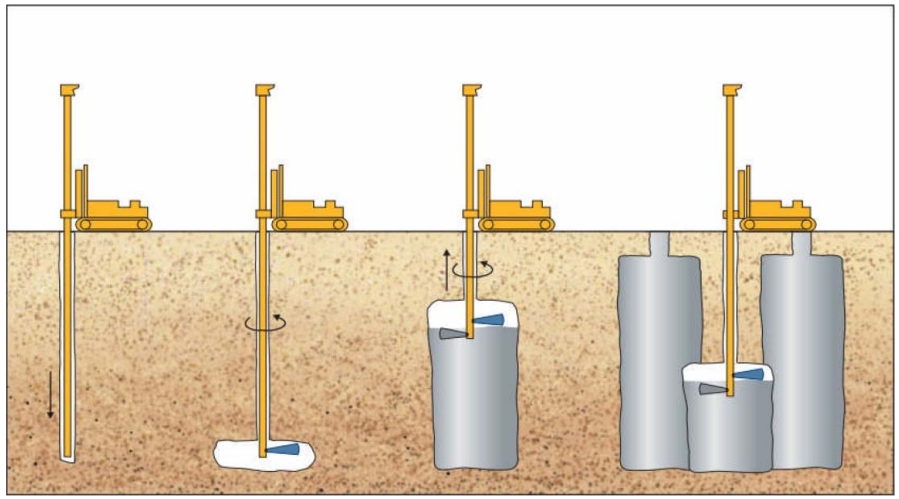
Spanish test site

- Subgrade stiffening under the track
  - Applied to railway tracks on soft soils to increase the subsoil stability and reduce settlements
  - Hydraulic fracture injection with stable cement-bentonite mixtures
  - Stiffening under the track: more efficient, but risk of track uplifting & interruption of train traffic

Spanish test site

- Subgrade stiffening next to the track
  - Construction of a jet grouting wall next to the track
  - Wave impeding barrier for railway induced vibrations

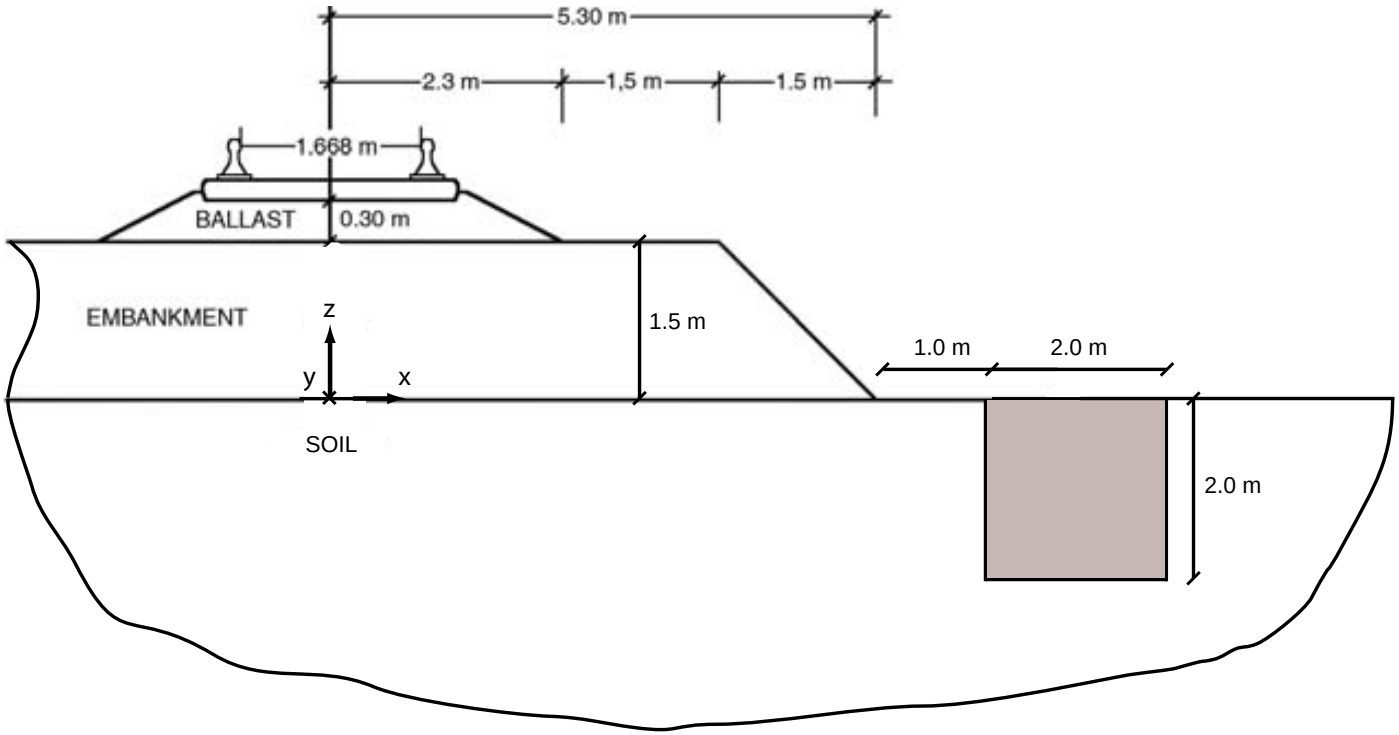




Buried wall barrier

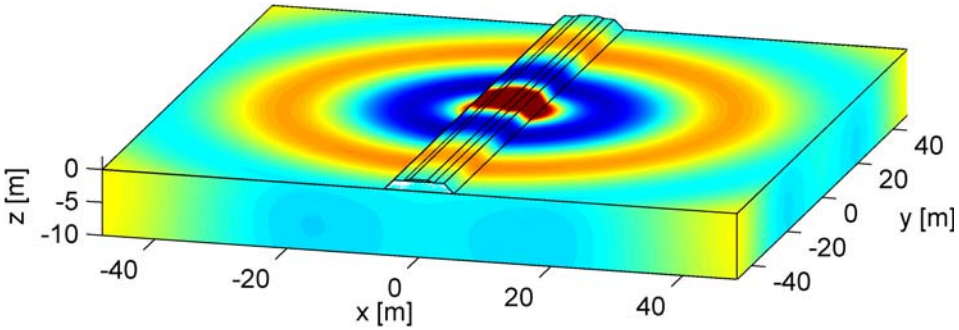
- Block of stiffened soil in homogeneous halfspace
  - Dynamic characteristics

	C_s [m/s]	C_p [m/s]	β_s [−]	β_p [−]	ρ [kg/m^3]
Halfspace	200	400	0.025	0.025	2000
Stiffened soil	550	950	0.05	0.05	2000

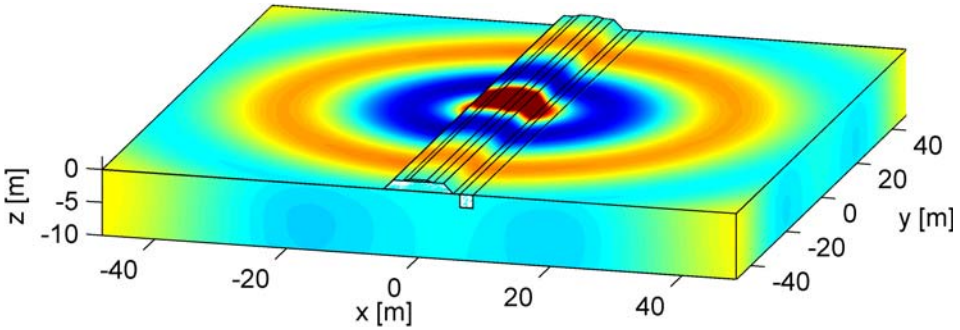


Buried wall barrier

- Vertical displacement at $5\,\mathrm{Hz}$



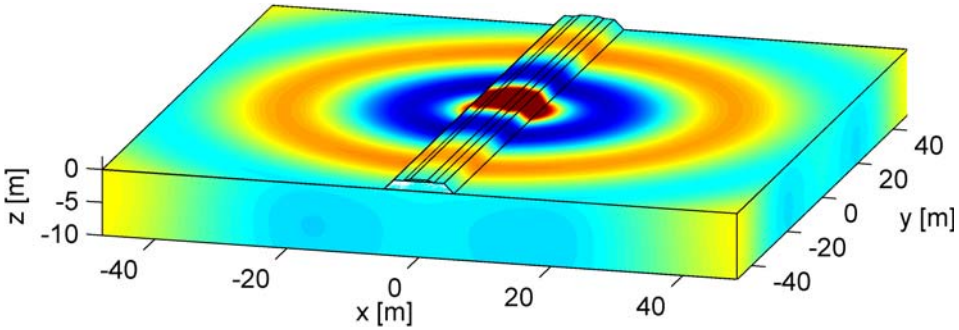
without barrier



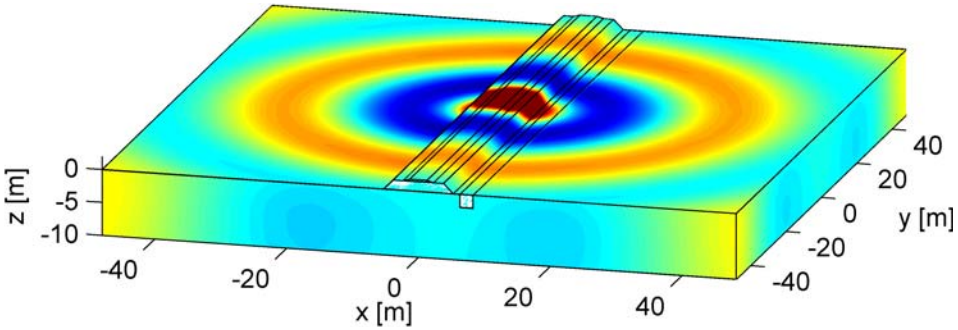
with barrier

Buried wall barrier

- Vertical displacement at $5\,\mathrm{Hz}$

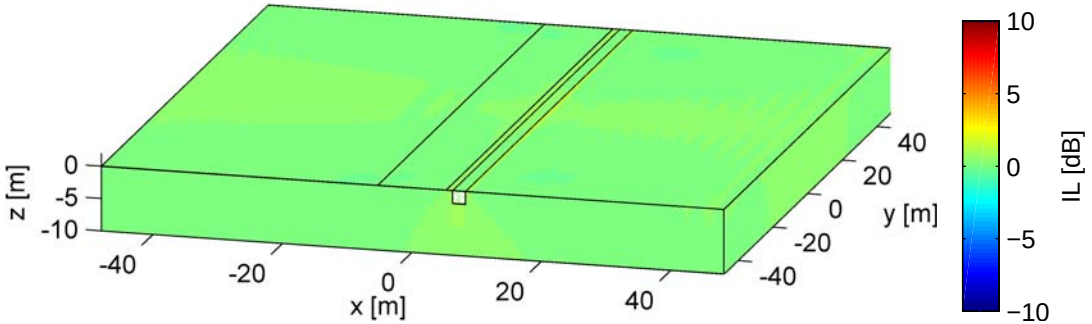


without barrier



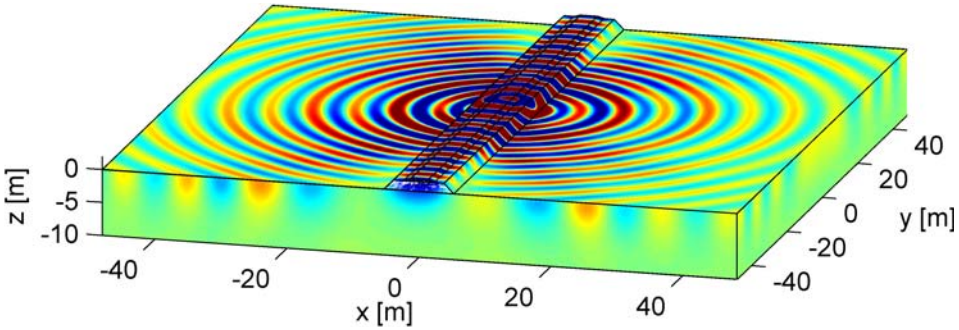
with barrier

- Corresponding insertion loss

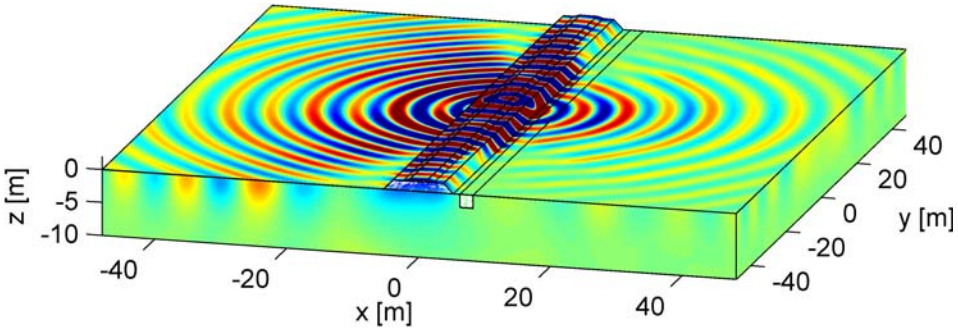


Buried wall barrier

- Vertical displacement at $30\,\mathrm{Hz}$

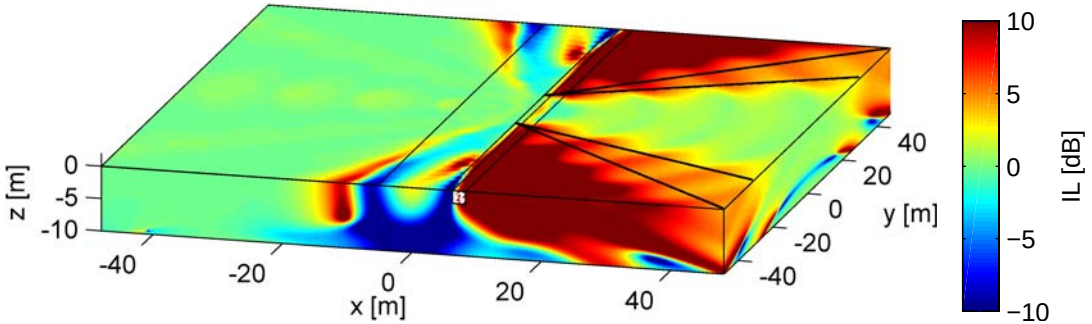


without barrier



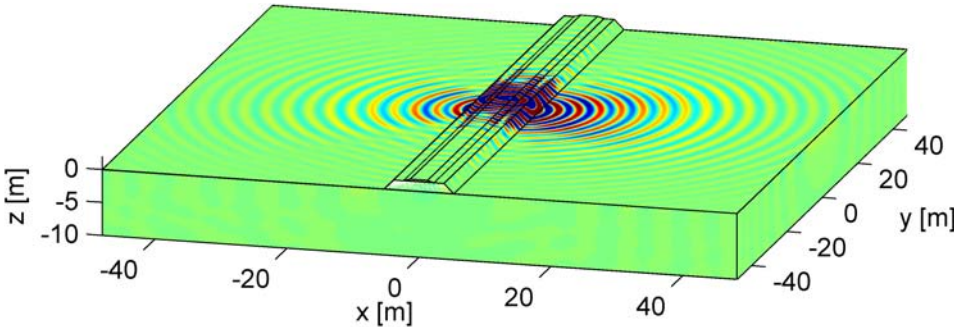
with barrier

- Corresponding insertion loss

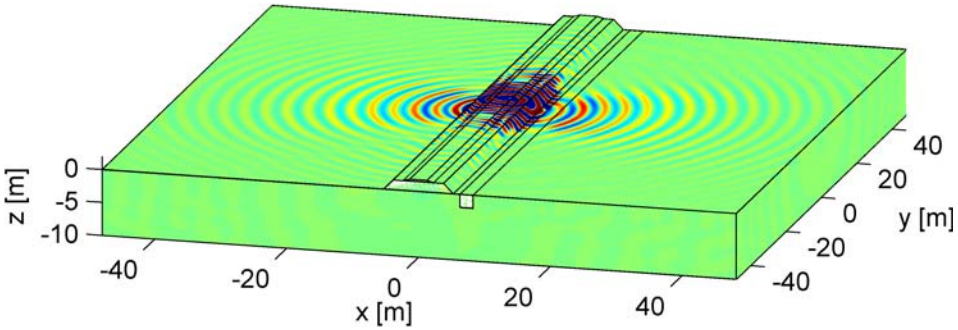


Buried wall barrier

- Vertical displacement at $60\,\mathrm{Hz}$

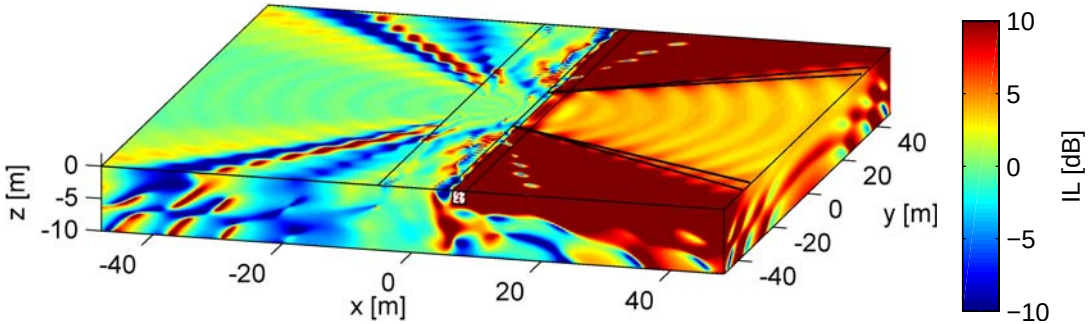


without barrier



with barrier

- Corresponding insertion loss



Spanish test site

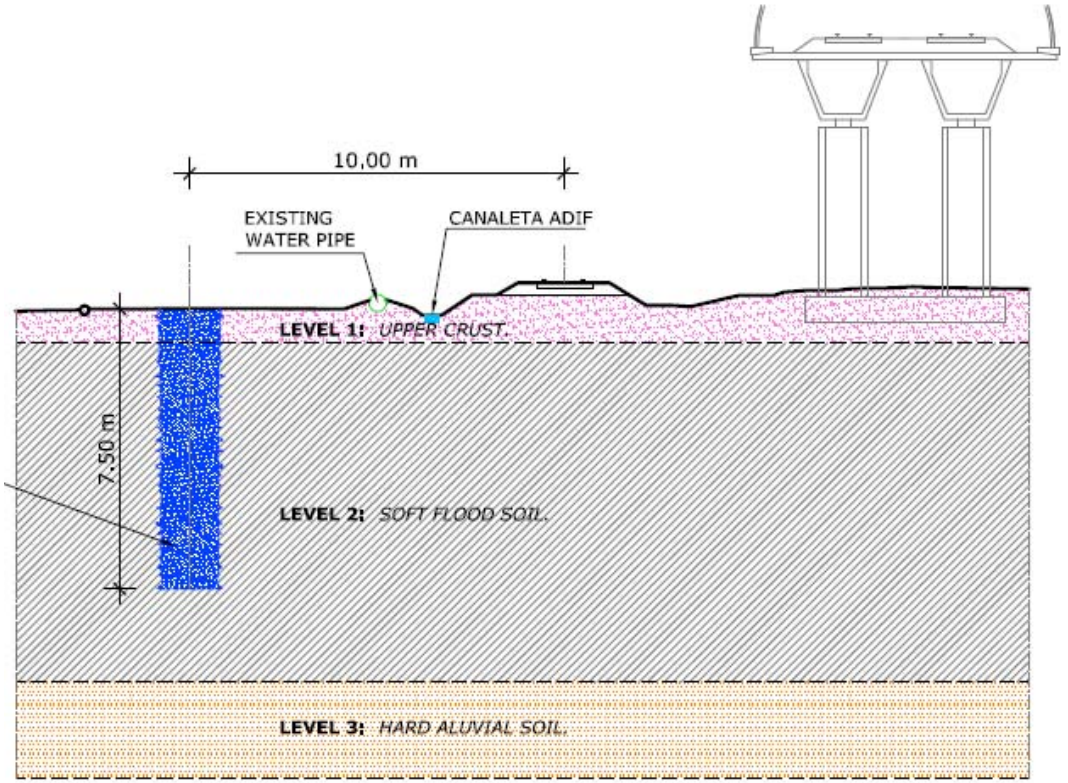
- El Realengo
  - Located between Murcia and Alicante
  - Conventional line, new HSL under construction

Spanish test site

- El Realengo
  - Soil characteristics

Layer	h [m]	C_s [m/s]	C_p [m/s]	ρ [kg/m^3]
1	0.30	270	560	1800
2	1.20	150	470	1750
3	8.50	150	1560	1750
4	∞	500	1560	1900

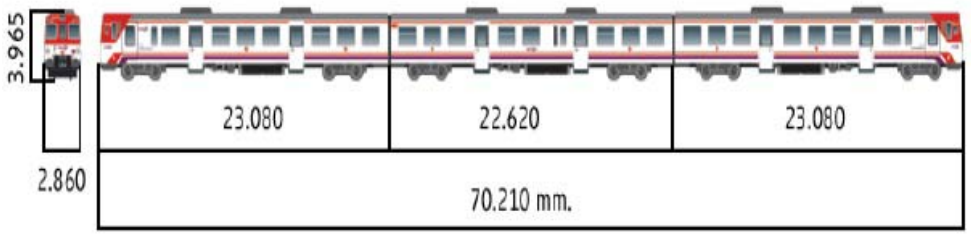
  - Superjet grouting wall
    - depth $5\,\mathrm{m}$, $7.5\,\mathrm{m}$, $10\,\mathrm{m}$
    - width $0.5\,\mathrm{m}$, $1.0\,\mathrm{m}$, $1.5\,\mathrm{m}$
    - shear wave velocity $C_\mathrm{s} = 400\,\mathrm{m/s}$, $650\,\mathrm{m/s}$



SECCIÓN 1-1'.

Spanish test site

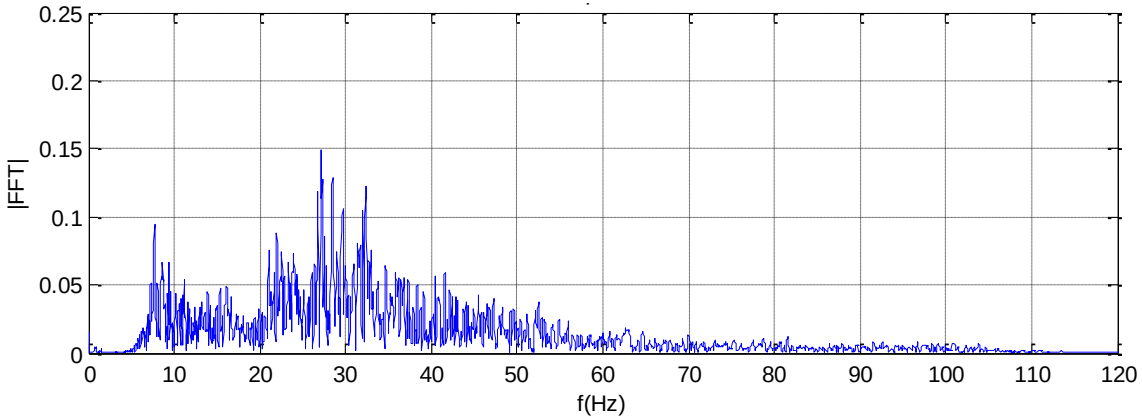
- Suburban train (category 592)



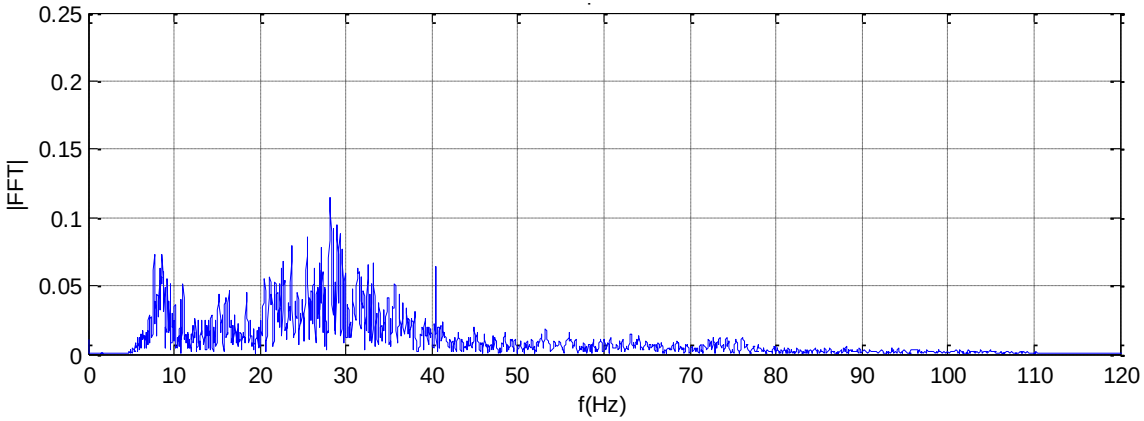
Spanish test site

- Measurement campaign (ADIF and CEDEX)
  - Free field velocity due to the passage of a suburbain train

12 m from the track

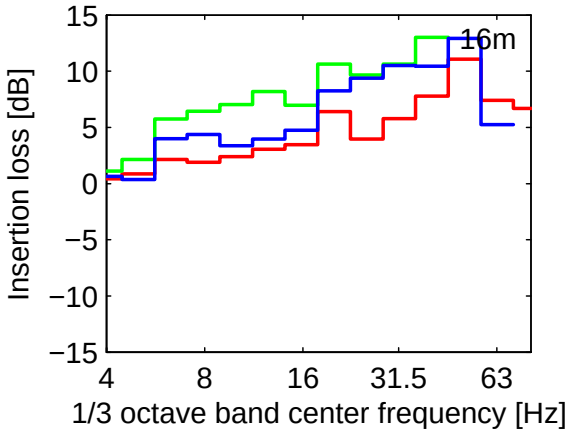


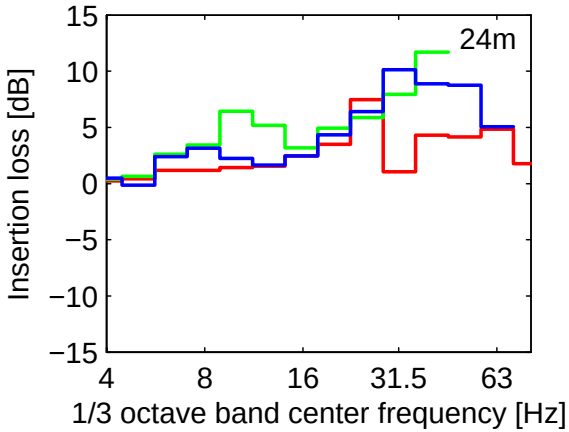
20 m from the track

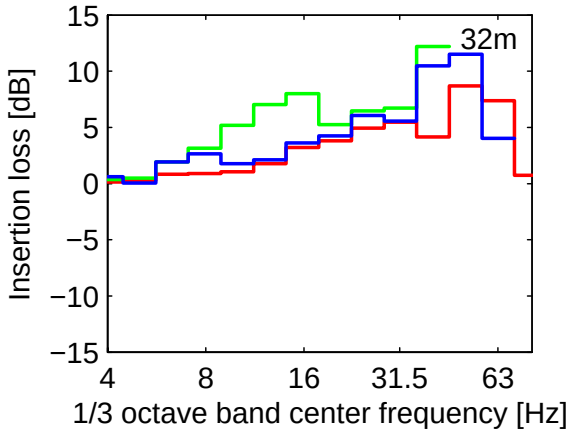


Spanish test site

- IL for passage of a suburban train at $120\,\mathrm{km/h}$
  - Influence of depth ($5\,\mathrm{m}$, $7.5\,\mathrm{m}$, $10\,\mathrm{m}$), width $1\,\mathrm{m}$, $C_\mathrm{s} = 650\,\mathrm{m/s}$







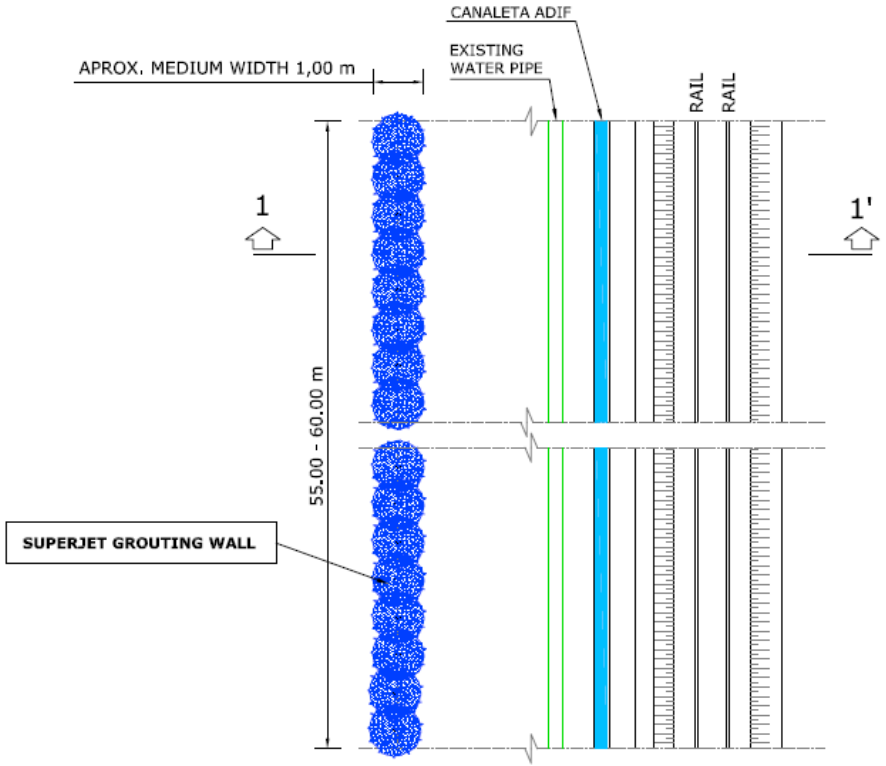
  - Numerical predictions indicate that subgrade stiffening can be effective at low frequencies (complementarity to other WPs)

Spanish test site

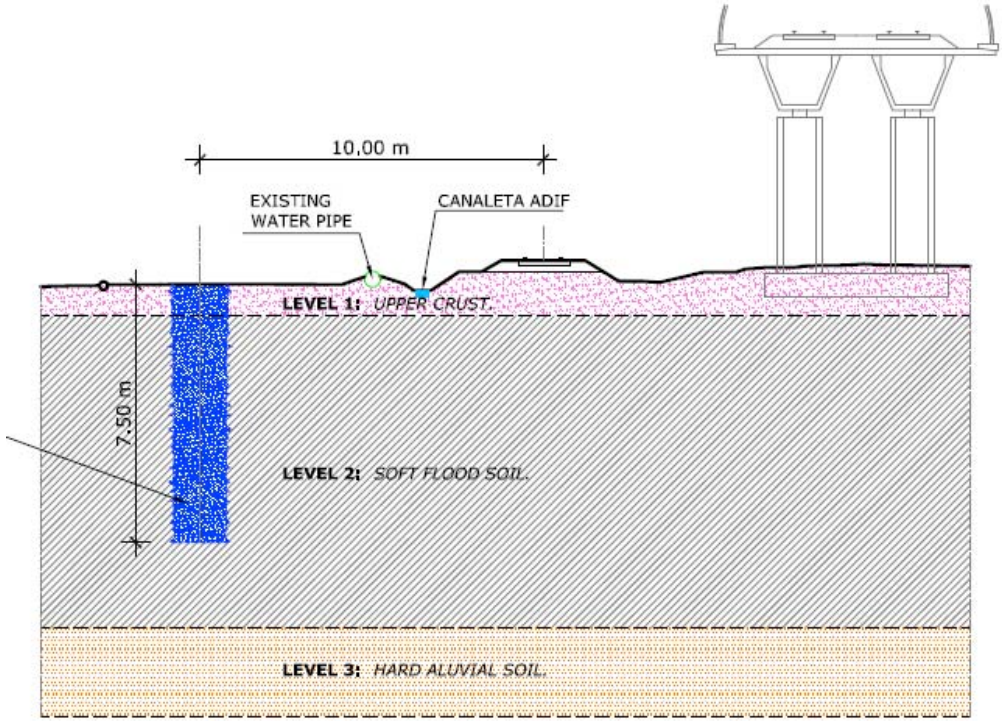
- Key parameters
  - Difference in stiffness between natural soil and stiffened soil (more effective at sites with a soft soil)
  - Depth of the wall (more effect than the width of the wall)
- Practical considerations
  - The jet grouting wall should be longer than the train length and at least one bending wave length
  - The jet grouting wall should be executed as a continuous block

Spanish test site

- Final design
  - Jet grouting wall with dimensions $60\,\mathrm{m} \times 1\,\mathrm{m} \times 7.5\,\mathrm{m}$



SUPERJET GROUTING WALL LAYOUT



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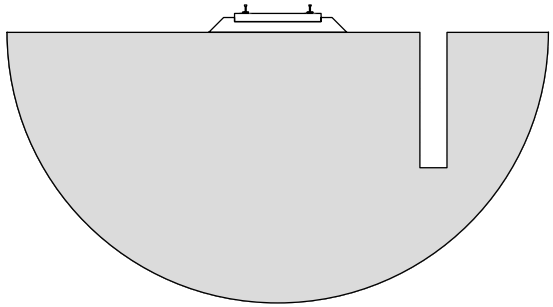
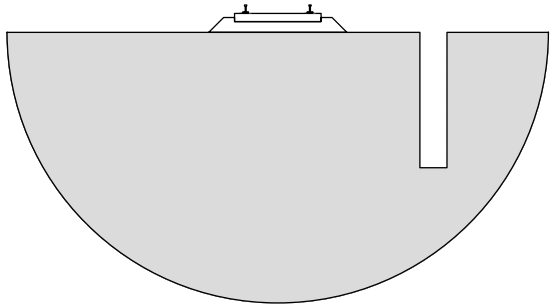
Swiss test site

- Trench barrier
  - Open, rectangular, unwalled trenches

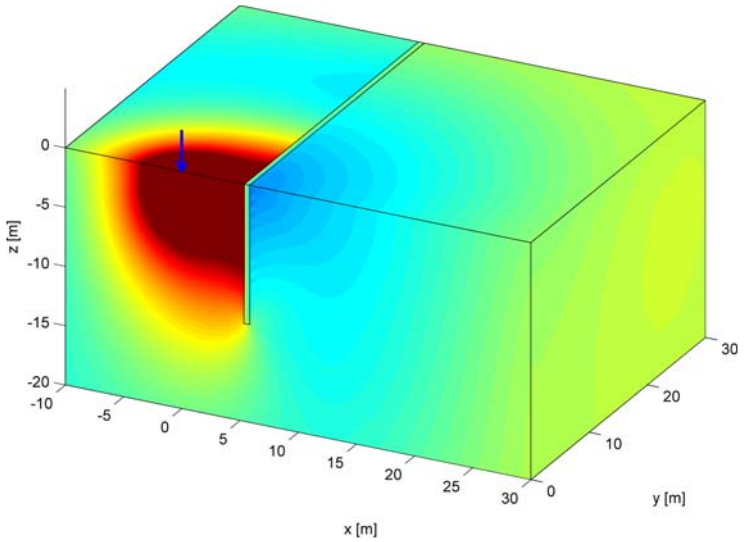


Swiss test site

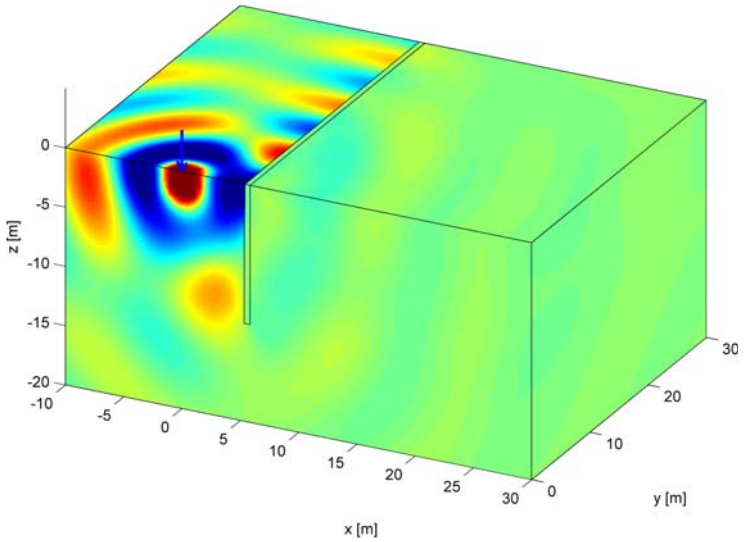
- Trench barrier
  - Open, rectangular, unwalled trenches
    - The depth should be at least 0.6 times the Rayleigh wavelength



$d = 0.25\lambda_R$

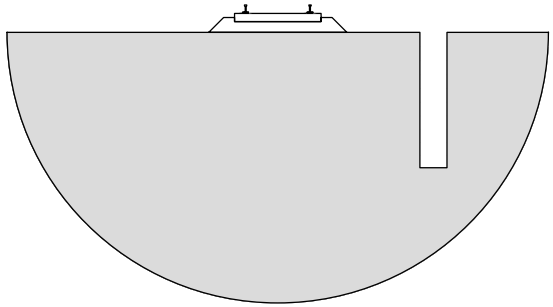


$d = 1.25\lambda_R$



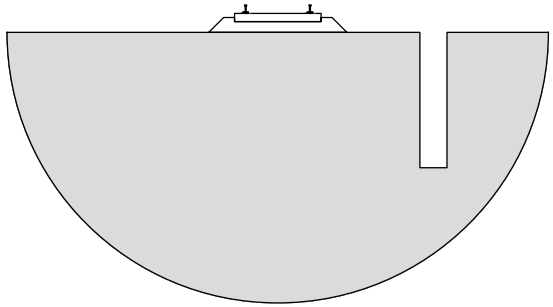
Swiss test site

- Trench barrier
  - Open, rectangular, unwalled trenches
    - The depth should be at least 0.6 times the Rayleigh wavelength
    - The width of the trench is only of secondary importance



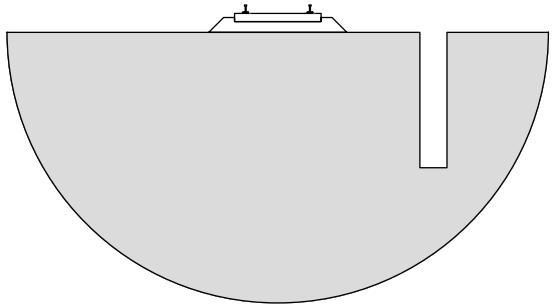
Swiss test site

- Trench barrier
  - Open, rectangular, unwalled trenches
    - The depth should be at least 0.6 times the Rayleigh wavelength
    - The width of the trench is only of secondary importance
    - Limited to shallow depths

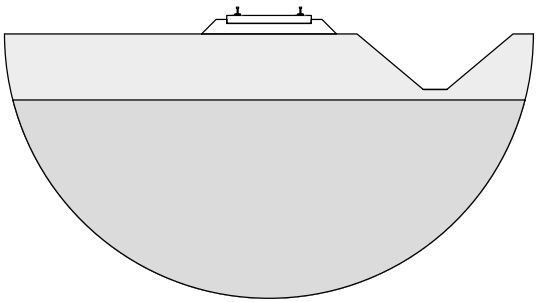


Swiss test site

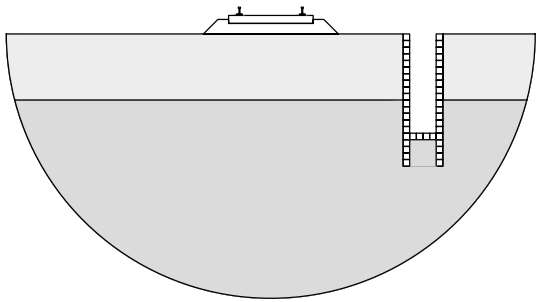
- Trench barrier
  - Open, rectangular, unwalled trenches
    - The depth should be at least 0.6 times the Rayleigh wavelength
    - The width of the trench is only of secondary importance
    - Limited to shallow depths
  - Feasible trenches



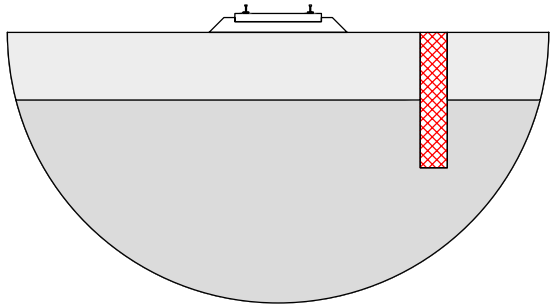
Sloping trench



Retaining structures

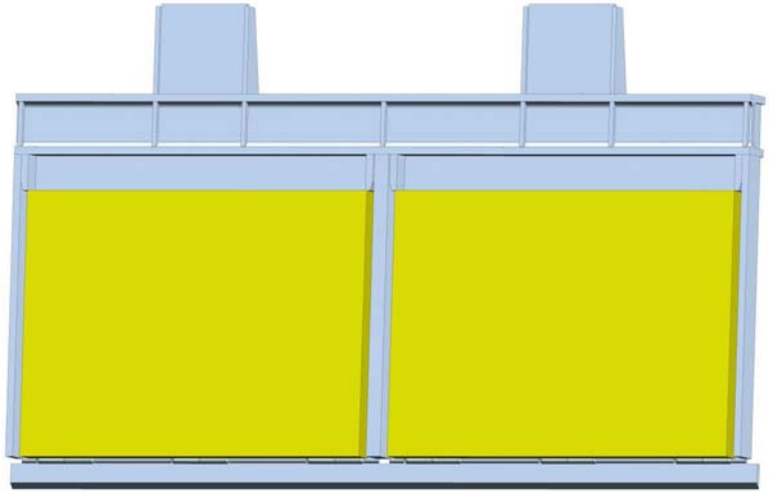


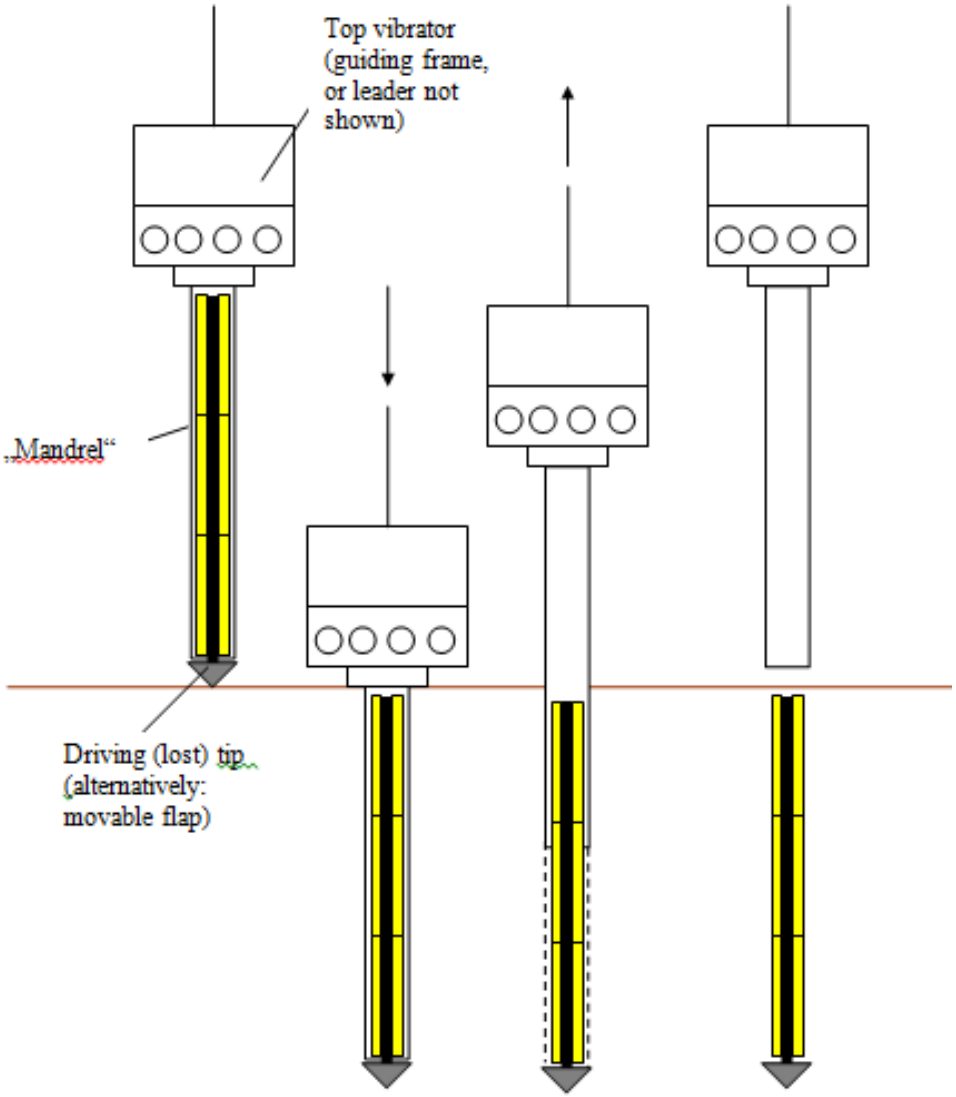
Soft or stiff in-fill material



Swiss test site

- Construction of trench with soft fill





Swiss test site

- Rubigen
  - Located near Bern

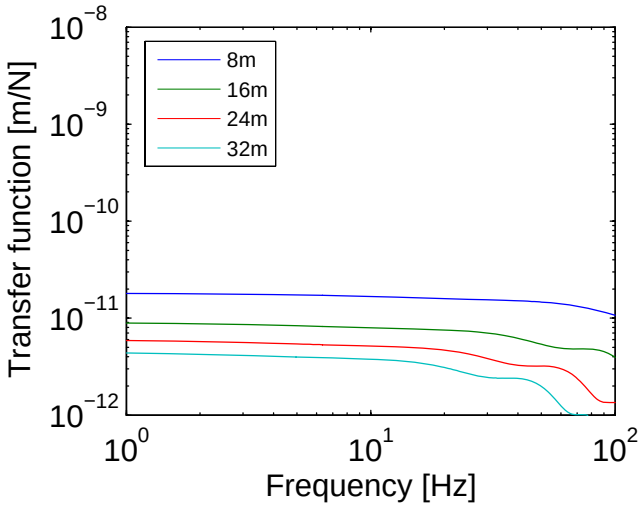
  - Soil properties
    - Soft upper layer with varying depth of $6 - 10\,\mathrm{m}$, overlaying a stiffer halfspace

	Shear wave speed C_s $[\mathrm{m/s}]$	Density ρ $[\mathrm{kg/m^3}]$	Poisson's ratio ν [-]	Damping ratio β [-]	Young's modulus E $[\mathrm{MPa}]$	Shear modulus μ $[\mathrm{MPa}]$
Layer 1	150	1800	0.33	0.03	107.73	40.5
Layer 2	600	2000	0.33	0.1	1915.2	720

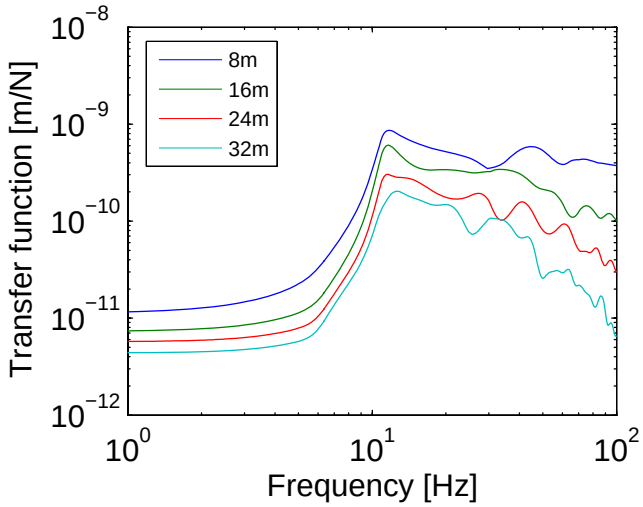
Swiss test site

- Transfer functions for Rubigen
  - Layered soil has great influence on wave propagation
  - Cut-on frequency (depending on soft layer depth)
  - Above this frequency, the surface waves are localized in the upper layer

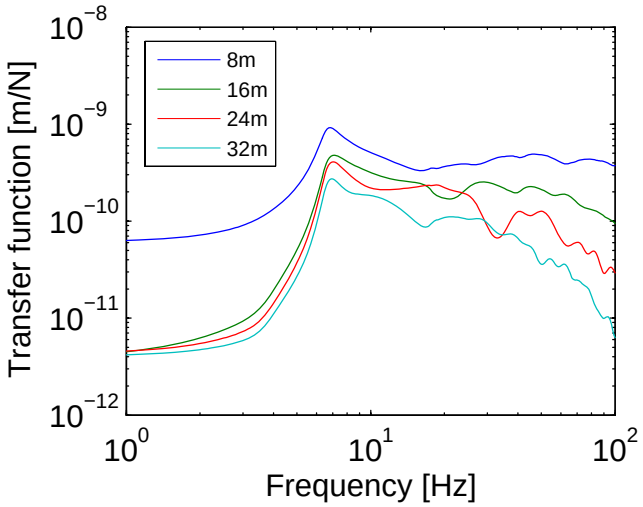
no soft layer



$6\,\mathrm{m}$ soft layer

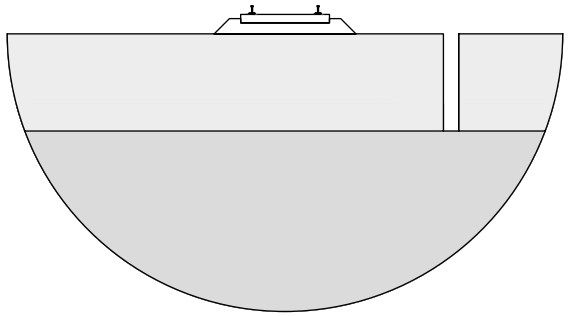


$10\,\mathrm{m}$ soft layer

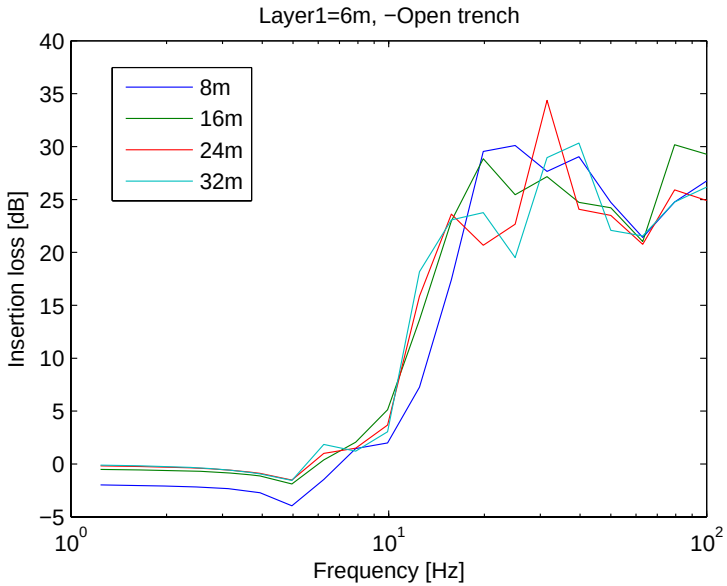


Swiss test site

- Preliminary design calculations
  - $6\,\mathrm{m}$ soft upper layer
  - $6\,\mathrm{m}$ deep open trench



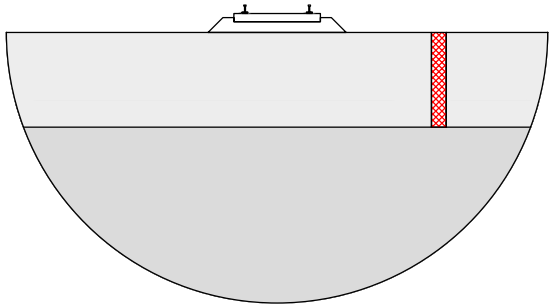
  - Vertical insertion loss
    - Large reduction above the cut-on frequency
    - Little additional benefit with deeper trench



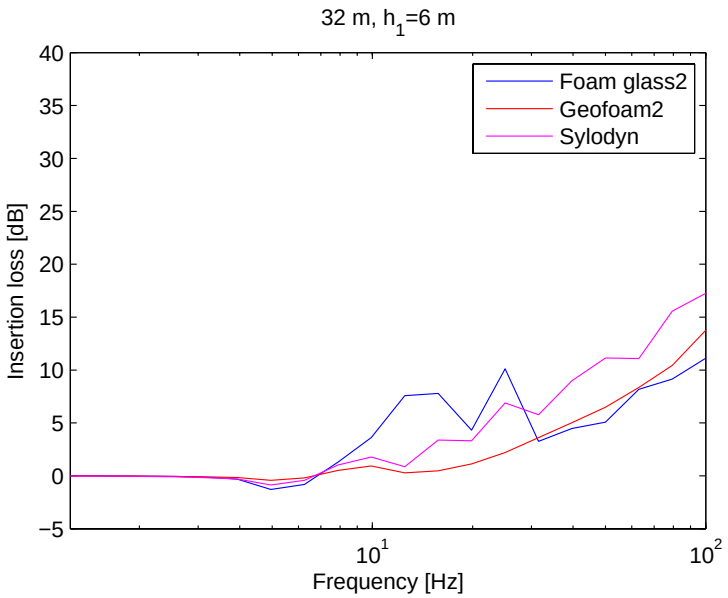
Swiss test site

- Preliminary design calculations
  - Influence of soft-fill material

	Shear wave speed C_s [m/s]	Density ρ [kg/m^3]	Poisson's ratio ν [-]	Young's modulus E [MPa]
Foam glass (25 cm)	50	133.4	0.4999	1
Geofoam (25 cm)	330	40	0.3065	11.38
Sylodyn NC (5 cm)	27.2	450	0.4	0.933



  - Vertical insertion loss
    - Soft fill gives a reduction of approximately $5\,\mathrm{dB}$ for frequencies $16 - 30\ \mathrm{Hz}$



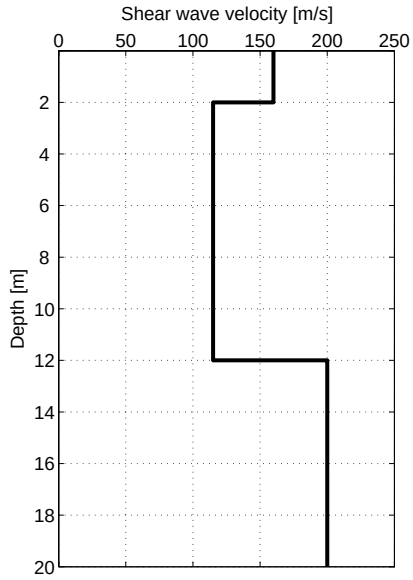
  - Possibility of other materials with lower stiffness is explored

Contents

- Introduction
  - Objective of RIVAS WP4
  - Methodology
- Test sites
  - Spain: subgrade stiffening next to the track
  - Switzerland: trench barrier
  - Sweden: sheet piling wall
- Conclusions and next steps

Swedish test site

- Furet
  - Located in southwest of Sweden (Halmstad) along the West Coast Line between Gothenburg and Lund
  - Vibration problems in houses nearby ($4 - 5\,\mathrm{Hz}$)

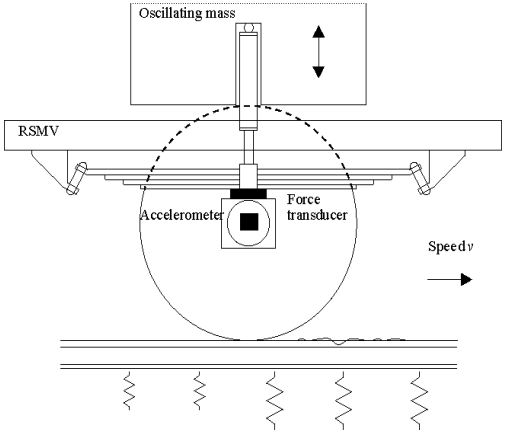


Swedish test site

- Furet
  - Sheet pile wall
    - Construction in November 2011
    - $12\,\mathrm{m}$ deep, every fourth pile extended to $18\,\mathrm{m}$

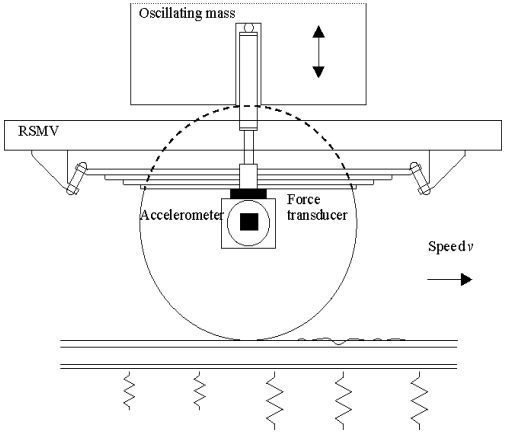
Swedish test site

- Measurements
  - Before and after
  - Artificial source (RSMV)
  - Train passages

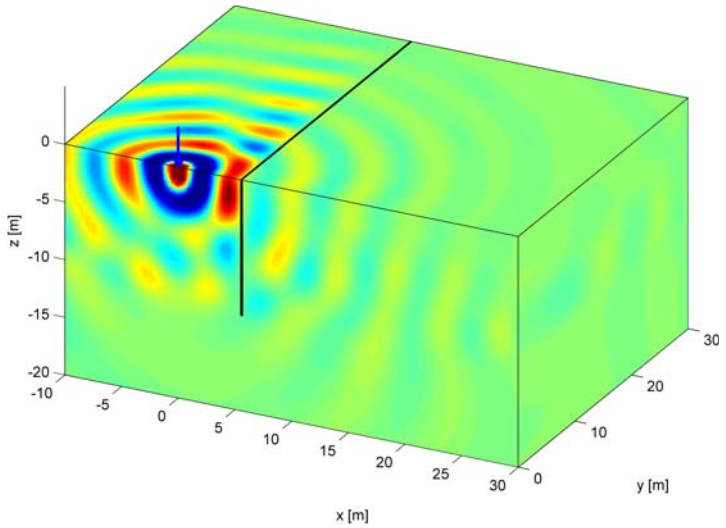


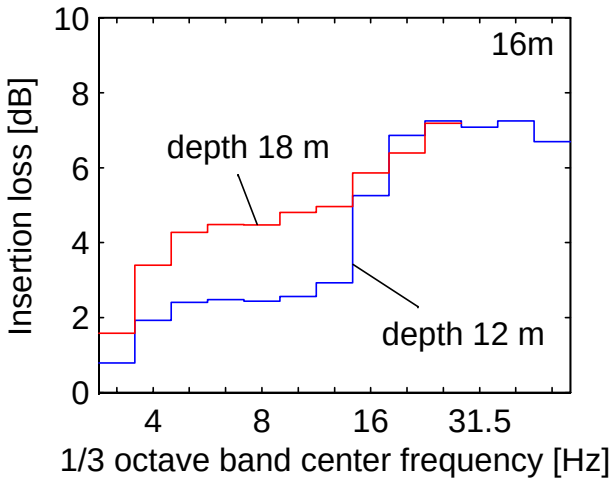
Swedish test site

- Measurements
  - Before and after
  - Artificial source (RSMV)
  - Train passages



- Simulations
  - Vertical displacement at $25\,\mathrm{Hz}$ and insertion loss at $16\,\mathrm{m}$





Conclusions

- Spanish test site
  - Numerical predictions indicate that subgrade stiffening at the test site in El Realengo can be very effective
  - Final design jet grouting wall with dimensions $60\,\mathrm{m} \times 1\,\mathrm{m} \times 7.5\,\mathrm{m}$
- Swiss test site
  - Preliminary design calculations have been performed for open trenches and trenches with soft-fill materials
  - Possibility of fill-in materials with lower stiffness is explored
- Swedish test site
  - Sheet piling wall was constructed in November 2011
  - Measurements and preliminary simulation results

Next steps

- Design of field tests
  - Design of mitigation measure at the Swiss test site
- Field tests
  - Construction and assessment of tests in Spain and Switzerland
- Parametric study
  - Subgrade stiffening under track
  - Wave impeding blocks
  - Masses next to track
- Design guide and technology assessment of transmission mitigation measures

Thank you for your attention

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